Proposed Alternative Method for Calculating Emissions from Hydraulic Fracturing Operations

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Outline

• Background on Reporting Greenhouse Gas (GHG) Emissions
• Analysis of EPA Equation
• Discussion of Alternate Method
• Analysis of Alternate Method as Confirmational Tool
• Analysis of Alternate Method as Predictive Tool
• Comparison of Alternate Model to Existing EPA Equation
Background

• EPA Mandatory Greenhouse Gas Reporting Rule
  • 40 CFR 98 Subpart W: Petroleum and Natural Gas Systems
  • Includes emission estimation methodologies and reporting requirements
  • GHG emissions include $N_2O$, $CH_4$ and $CO_2$ during flow back after hydraulic fracturing

• Hydraulic Fracturing: Fracturing rock using pressurized liquid to stimulate a well to maximize oil and gas extraction
  • Flowback: Process of removal of spent fluids (wastewater, produced water, etc.) prior to well production
Flow Back Process Flow Diagram
Three Phase Separator
Frac, Water and Oil Tanks
Produced Gas Flow Meter
Produced Gas Flare
Existing EPA Methodology (1 of 2)

• Option 1: Measure and record GHG emissions from each fractured well

• Option 2: Measure and record GHG emissions from subset of wells, and extrapolate to other wells
  • Measurements cost on the order of $5,000 per day at each site

• Option 3: Calculate emissions in lieu of performing measurements
Existing EPA Methodology (2 of 2)

• Option #3: EPA Equations W-11A and W-11B

• Subsonic Flow (W-11A)

\[
FR_a = 1.27 \times 10^5 \cdot A \cdot \sqrt{3430 \cdot Tu \cdot \left[\left(\frac{P_2}{P_1}\right)^{1.515} - \left(\frac{P_2}{P_1}\right)^{1.758}\right]}
\]

• Sonic Flow (W-11B)

\[
FR_a = 1.27 \times 10^5 \cdot A \cdot \sqrt{187.08 \cdot Tu}
\]

• Both equations calculate an actual volumetric gas rate

• Assume sonic flow applies \((P_1/P_2 > 2)\) and use Eq. W-11B
Why Explore Alternatives to EPA Equations?

- EPA Equations
  - Appear to be derived from ideal gas law
  - Assume single-phase, methane gas
- Flowback following hydraulic fracturing
  - Multiple fluid phases (gas, oil, water)
  - Variable flow rate
  - Variable composition
- Result: EPA Equation W-11B typically overestimates GHG emissions
Alternative: Empirically Derived Relationships

• Gilbert-type Correlation (1954)
  • Multiphase flow through wellhead choke
  • General form

\[ P = \frac{c \times Q_L \times R^a}{S^b} \]

- \( P \) = upstream pressure (psia)
- \( Q_L \) = gross liquid rate (barrels per day)
- \( R \) = gas to liquid ratio (Mscf/bbl)
- \( S \) = choke size (1/64” increments)
Empirical Data Analysis

• Step 1: Collect measured data for upstream pressure, choke size, and oil, water and gas production rates

• Step 2: Convert Gilbert-type correlation to linear form

\[
\ln(P) - \ln(Q_L) = \ln(c) + a \times \ln(R) - b \times \ln(S)
\]

• Step 3: Solve for a/b/c coefficients using multivariable linear regression

• Step 4: Rearrange and solve for gas rate

\[
Q_G = Q_L \times \left(\frac{P \times S^b}{c \times Q_L}\right)^{1/a}
\]

• Step 5: Compare measured gas rate to calculated gas rate
Site-Specific Data Collection

• 13 total flowback operations
  • Ten high flow rate operations
  • Three low flow rate operations

• Measured data recorded hourly
  • Tubing pressure, choke size, cumulative gas/oil/water produced

Removed periods of atypical operation from analysis
Atypical Operation: Examples

No multiphase flow

No flow
Analysis of Site-Specific Data

• Calculate seven-day averages for collected data
  • Tubing pressure (psia)
  • Choke size (1/64” increments)
  • Daily gas production (Mscf/day)
  • Daily water production (bbl/day)
  • Daily oil production (bbl/day)

• Calculate gas to oil ratio, gross liquid rate for seven-day averages

• Regress data to calculate a/b/c coefficients and compare calculated gas production to measured gas production
Results of Site-Specific Data Analysis

<table>
<thead>
<tr>
<th>Site</th>
<th>Measured Cumulative Gas Volume (MMscf)</th>
<th>Predicted Cumulative Gas Volume Site-Specific Correlation (MMscf)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noble Well 1</td>
<td>81</td>
<td>88</td>
<td>9</td>
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<tr>
<td>Noble Well 2</td>
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<tr>
<td>Field Total / Error Value</td>
<td>694</td>
<td>722</td>
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</tbody>
</table>

- Gilbert-type correlation provided excellent results when using site-specific coefficients
- Valid for use as confirmational tool
Extend Analysis to Entire Field

• Analysis of site-specific data only confirms that the correlation is valid when using site-specific coefficients.

• Analysis of field-wide data was necessary to assess accuracy of correlation as predictive tool for other wells in the same field.
Analysis of Field-Wide Data

- Created composite data set of seven-day averages from ten long-term flowback operations
- Regressed one single set of a/b/c coefficients using data from all ten, high flow rate wells
### Results of Field-Wide Data Analysis

<table>
<thead>
<tr>
<th>Site</th>
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- Using field-regressed coefficients is satisfactory
- More variability with field-wide than site-specific coefficients
Parity Plot

![Parity Plot Diagram]

- Measured Gas Flow Rate (MSCF/day)
- Predicted Gas Flow Rate (MSCF/day)

- Site-Specific Coefficients
- Field-Wide Coefficients
EPA Equation W-11B

- Equation W-11B calculates emissions as a function of average upstream temperature and choke size.
- Equation W-11B has a consistent, high bias compared to measured emissions.

<table>
<thead>
<tr>
<th>Site</th>
<th>Cumulative Measured Gas Volume (MMscf)</th>
<th>EPA Eq. W-11B (MMscf)</th>
<th>EPA Eq. W-11B Error (%)</th>
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Comparison of Empirical Methods with Equation W-11B

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Empirical method was consistently more accurate than EPA Equation W-11B for these data.
Summary

• Gilbert-type correlation can be used to predict overall volume of gas produced during flowback operations

• Gilbert-type correlation was sufficiently accurate at site-specific and field-wide levels
  • Variables required: choke size, tubing pressure, total produced liquid

• Gilbert-type correlation is more complicated than Equation W-11B
  • Requires linear regression
  • Requires engineering judgment to exclude data from periods of atypical operations

• EPA Equation W-11B consistently overestimated overall volume of gas produced for the wells studied

• Predictive correlation should be tested and validated using data from other formations to confirm its applicability in other formations and fields
Acknowledgements

• Thanks to Noble Energy
• Further Detail: SPE-166432-MS